Cooperating Objects NETwork of Excellence
7th Framework Programme
FP7-224053

The WSN standards and COTS landscape: can we get QoS and “calm technology”? 

Tutorial@EWSN’09
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Where do I come from...

Somewhere around here
(Porto, Portugal)

knew about these?
Cork and Porto have a lot in common 😊

About my research unit

CISTER

Research Centre in Real-Time Computing Systems

http://www.cister.isep.ipp.pt
About my research unit – research areas

- **What are Real-time Computing Systems?**
  - real-time computing systems are those systems where correctness depends not only on the correct production of logical results but also on the time when those results are produced
  - e.g. transportation, factory automation, medical, security, audio/video streaming, robotics

- **Main research areas:**
  - single/multi-core/multi-processor systems
  - real-time languages and operating systems
  - scheduling and schedulability analysis
  - wireless sensor/actuator networks
  - cyber-physical systems

About my research unit – other partnerships

- **EMMON (ARTEMIS programme)**
  - large-scale embedded monitoring using WSNs
  - MAR/2009 – FEB/2012
  - 8 partners: Critical Software (PT), Intesys (UK), Trinity College Dublin (IR),…

- **ARTISTDesign (EC NoE)** [http://www.artist-embedded.org](http://www.artist-embedded.org)
  - embedded systems design
  - JAN/2008 – JAN/2012 (4 years)
  - 30 partners: OFFIS (D), a PAREDES (I), Centre de Energie Atomique (F), U. Uppsala (S), U. York (UK), U. Lund (S), U. Bolonha (I), U. Lausanne (CH), …
  - Headed by Prof. Joseph Sifakis, 2007 ACM Turing Award

- **PT-CMU (Carnegie Mellon University)** [http://www.cmuportugal.org](http://www.cmuportugal.org)
  - networked sensor, communication and decision systems for monitoring critical physical infrastructures
  - JAN/2007 – FEB/2012 (5 years)

- **TinyOS Net2, ZigBee and IEEE 802.15.4 Working Groups**
  - leading IEEE 802.15.4/ZigBee protocol stack
  - since 2006 (in Net2 WG), since 2009 (802.15.4 and ZigBee WGs)
  - [http://www.tinyos.net](http://www.tinyos.net), [http://www.open-ZB.net](http://www.open-ZB.net)
About CONET

- Network of Excellence funded in FP7 (INFSO-ICT-224053)
  - 1/JUN/2008 – 31/MAY/2012 (48 months)
  - EC approved funding: 4 MEuro
  - Total Budget: 10.4 MEuro
  - 16 core partners: key academic and industrial players
  - Very strong Industrial and External Advisory Boards
  - More information: http://www.cooperating-objects.eu

About CONET – core partners
About CONET – areas

Pervasive Computing
Cooperating Objects
Sensor Networks
Embedded Systems

About CONET – current research clusters

Hardware
Testbed and Simulation Platforms for Cooperating Objects *
Deployment and Management of Cooperating Objects *
System
http://www.cooperating-objects.eu/research-clusters
Ubiquitous Integration of Cooperating Objects *
Resource Management and Adaptation *
Non-functional Properties

Mobility of Cooperating Objects *
Recognizing Emotions using WSNs
Algorithms
Scalable Data Processing *
COTS-based Architecture for QoS

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Acknowledgements

- EWSN’09
  - Cormac Sreenan/Utz Roedig (General co-Chairs)
- CONET
  - Pedro Marron (CONET coordinator)
  - COTS4QoS research cluster (particularly Gianluca Dini and Ida Savino, UNIPI)
- CISTER
  - Ricardo Severino, Anis Koubâa, Nouha Baccour, Nuno Pereira, Petr Jurcik, Björn Andersson, Shashi Prabh, Eduardo Tovar

About the title of the talk (1)

- The wireless sensor networks standards and COTS landscape: can we get QoS and “calm technology”?
About the title of the talk (2)

- what are “wireless sensor/actuator networks”?
  - “wireless (communication)”
    - “wireless communication” is the transfer of information over a distance without the use of electrical conductors or “wires” using some form of energy, e.g. radio frequency (RF), infrared light (IR), laser light, visible light, acoustic energy
  - “sensor”
    - a sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument, e.g. thermocouple, strain gauge;
    - sensors tend to be manufactured on a microscopic scale (MEMS technology)

About the title of the talk (3)

- what are “wireless sensor/actuator networks”? (cont.)
  - “actuator”
    - devices which transform an input signal (mainly an electrical signal) into motion
    - e.g. electrical motors, pneumatic actuators, hydraulic pistons, relays, electro-valves, piezoelectric actuators, buzzers, lamps
  - “network”
    - a “computer network” is a group of interconnected computers
About the title of the talk (4)

- what are “wireless sensor/actuator networks”? (cont.)
  - “wireless sensor network”
    - A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations.
    - originally motivated by military applications such as battlefield surveillance; now used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, and traffic control

About the title of the talk (5)

- what are “wireless sensor/actuator networks”? (cont.)
  - “sensor node”
    - a sensor node (a.k.a. “mote”), is a node in a wireless sensor network that is capable of performing some processing, gathering sensory information and communicating with other connected nodes in the network
    - in addition to one or more sensors, each node in a sensor network is typically equipped with a radio transceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery.
About the title of the talk (6)

- what are “standard and COTS technologies”?
  - “technology”
    - “is a broad concept that deals with a species’ usage and knowledge of tools and crafts, and how it affects a species’ ability to control and adapt to its environment. In human society, it is a consequence of science and engineering”
  - “standard”
    - “A technical standard is an established norm or requirement. It is usually a formal document that establishes uniform engineering or technical criteria, methods, processes and practices.”
  - “COTS”
    - “Commercial, off-the-shelf (COTS) is a term for software or hardware, generally technology or computer products, that are ready-made and available for sale, lease, or license to the general public.”

About the title of the talk (7)

- but why using “standard and COTS technologies”?
  - for reducing the development and maintenance costs
    - we can buy them (or get them for free – open-source)
  - for increasing interoperability
    - with what other people (industry/academia) is doing
  - for speeding up their utilization and deployment
    - in real world applications
    - by system developers (love COTS)
    - by end-users (hate new/immature things)
About the title of the talk (8)

- what is “Quality-of-Service (QoS)”?
  - traditionally, “QoS is the ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. …”
    - “… For example., a required bit rate, delay, jitter, packet dropping probability and/or bit error rate may be guaranteed…”
    - “…QoS guarantees are important if the network capacity is a limited resource…” (isn’t it always?)
  - “e.g. voice over IP, online games and IP-TV”

- but we will look at QoS in a different way (later on)

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About the title of the talk (9)

- what is “calm technology”?
  - “the most profound technologies are those that disappear; they weave themselves into the fabric of everyday life until they are indistinguishable from it”
  - the term “calm technology” was coined by Mark Weiser (“The computer of the 21st Century”, Scientific American, 1991), in his early visions on ubiquitous computing
  - actually, common people do not want to know how a car, a pen or a computer works; they just want to be served properly, with the best quality possible.
About the title of the talk (10)

- So, wrapping up:
  - we will reason about
    - how to achieve
      **QoS and „calmness“**
  - by using
    **standard and COTS WSN technology**

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Tutorial outline

- **ICT trends**
  - some visions on the evolution and threats of ICT technology

- **WSN technology**
  - an outlook of WSN types, topologies, routing, MAC, PhL, motes, transceivers, RFID, MEMS, OS, comm. protocols

- **Quality-of-Service**
  - a holistic approach

- **On-going work**
  - related CONET activities
ICT trends (1)

- Imagination is the limit…
  - **Arthur C. Clarke's Laws**
    - (1917-2008):
      - “When a distinguished but elderly scientist states that something is possible he is almost certainly right. When he states that something is impossible, he is very probably wrong”
      - “The only way of discovering the limits of the possible is to venture a little way past them into the impossible”
      - “Any sufficiently advanced technology is indistinguishable from magic”

ICT trends (2)

- and ICTs trend may help…
  - **Gordon Moore's Law**
    - (born 1929):
      - “The number of transistors that can be inexpensively placed on an integrated circuit is **increasing exponentially**, doubling approximately every two years” (paper from 1965)
      - In 2005, he stated that the law **cannot be sustained indefinitely** and noted that transistors would eventually reach the **limits of miniaturization** at atomic levels
ICT trends (3)

- and ICTs trend may help...
  - Gordon Bell’s Law (born 1934)
    - “Roughly every decade a new, lower priced computer class forms based on a new programming platform, network, and interface resulting in new usage and the establishment of a new industry” (paper from 1972)
  - “As of 2005, computer classes include:
    - mainframes (1960s)
    - minicomputers (1970s)
    - PCs and workstations evolving into a network enabled by Local Area Networking (1980s)
    - web browser client-server structures enabled by the Internet (1990s)
    - small form-factor devices such as cell phones and other cell phone sized devices (c. 2000)
    - wireless sensor networks, aka motes (c. >2005)
    - home and body area networks (> 2010)”

ICT trends (4)

- and ICTs trend may help...
  - Robert Metcalfe’s Law (born 1946):
    - “the value of a network grows as the square of the number of its users”
ICT trends (5)

- but be very careful with the consequences…
  - Edward Murphy’s Law (1918-1990):
    - “If there are two or more ways to do something, and one of those ways can result in a catastrophe, then someone will do it” (original version, c. 1952)

ICT trends (6)

- but be very careful with the consequences…
  - George Orwell’s “vision” (1903-1950):
    - “BIG BROTHER IS WATCHING YOU” (‘1984’ book, pub. 1949)
    - vision of all-knowing governments which uses pervasive and constant surveillance of the populace
ICT trends (7)

- but be very careful with the consequences…
    - “a robot may not injure a human being or, through inaction, allow a human being to come to harm”
    - “a robot must obey orders given to it by a human being except where such orders would conflict with the first law”
    - “a robot must protect its own existence as long as such protection does not conflict with the first or second laws”

ICT trends (8)

- so do not forget…
  - Mark Weiser (1952-1999):
    - principles of ubiquitous computing:
      - “the purpose of a computer is to help you do something else; the best computer is a quiet, invisible servant”
      - “the more you can do by intuition the smarter you are; the computer should extend your unconscious”
      - “technology should create calm”
    - major trends in computing
      - “ubiquitous computing names the third wave in computing, just now beginning. First were mainframes…. Now we are in the personal computing era…. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives”

Are you ready for things you did not see yet?

Are you ready to watch the world from a ≠ angle?
WSN technology

From "traditional" WSN to other "forms":
- Body Sensor Networks (BSN)
- Vehicular Sensor Networks (V2V, V2I)
- Machine-to-Machine (M2M)
- Underwater (Acoustic) Sensor Networks (UW-ASN)
- Internet-of-Things (pervasive Internet)
- Urban/social/participatory Sensor Networks
- Interplanetary Sensor Networks
- Fieldbus Networks (the good oldies are getting wireless/mobile capabilities and scaling up)
- Networks-on-Chip (NoC)
- Near-Field Communications (NFC)
WSN technology – WSN topologies

- Overview

**WSN Architectures**

- **Flat**
  - Mesh, Ad-Hoc Peer-to-Peer

- **Hierarchical**
  - Multi-Tier
  - Cluster-Based
  - Cluster-Tree
  - Hexagonal

**Flat**

- no infrastructure
- peer-to-peer (flat) routing
- very flexible
- low management complexity
- limited QoS guarantees
- all nodes have the same role
- basically, contention-based MAC protocols (e.g., CSMA/CA, Aloha)
- unsynchronized or synchronized (e.g., S-MAC)

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### WSN technology – WSN topologies

#### Cluster-tree
- Network infrastructure: Backbone
- Hierarchical routing
- Low flexibility
- Good QoS support
- Complex network management
- Basically, contention-FREE MAC protocols (TDMA)
- Synchronized (e.g., LEACH)
- Nodes have different roles, e.g., coordinator, sink, router, leaf

#### Multiple-tiered
- Tier-1: sensor network
- Tier-2: backbone network
- Tier…: Internet?
WSN technology – WSN topologies

- **Hexagonal**
  - each node has six neighbors except for nodes at the edges
  - in the event of arbitrary deployments, consider a two-tier hierarchy
    - upper layer consists of nodes in hexagonal topology which are cluster heads
    - lower layer consists of the nodes that belong to one of the clusters
    - cluster heads route data over multiple hops
  - benefits of hexagonal WSN:
    - simple/low overhead MAC/network protocols
    - easy to guarantee real-time communications

WSN technology – routing aspects

- **Routing classification – destination**
  - **unicast** (delivers a message to a single specified node)
  - **broadcast** (delivers a message to all nodes in the network)
  - **multicast** (delivers a message to a group of nodes that have expressed interest in receiving the message)
  - **convergecast** (disseminates and aggregates data towards a sink)

- **Routing classification – determinism**
  - **probabilistic**
    - routing path may vary with time (node/network status); e.g., AODV
  - **deterministic**
    - unique routing path from any source to any destination (though nodes connectivity may be much larger); e.g., tree routing
WSN technology – routing aspects

- Routing classification – dynamics
  - proactive (first compute all routes; then route)
  - reactive (compute routes on-demand)
  - hybrid (first compute all routes; then improve while routing)

- Routing classification – architecture
  - direct (node and sink communicate directly)
    - fast drainage; small scale
  - flat (equal; random indirect route)
    - fast drainage around sink; medium scale
  - clustering (hierarchical; route through distinguished nodes)

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WSN technology – routing aspects

- Routing classification – location-awareness
  - location-aware (nodes knows where they are)
  - location-less (nodes location is unimportant)
  - mobility-aware (nodes may move (sources; sinks; all))

- Routing classification – addressing
  - data-centric
    - the sink sends queries to certain regions and waits for data from the sensors located in the selected regions
    - data aggregation during the relaying of data
  - address-centric
    - routes are created between addressable nodes managed in the network layer of the communication stack.
WSN technology – MAC aspects

- MAC classification (do you like this one?)

MACs

Contention-based
  - Destructive collisions
    - e.g. CSMA family, e.g. IEEE 802.3, 802.11, IEEE 802.15.4 CSMA/CA
  - Non-destructive collisions
    - e.g. CAN (cars), HomePlug (domotics), WiDOM (wireless)

Contention-free
  - TDMA
    - Pre-scheduled
      - TDMA family, e.g. GSM, Bluetooth, WiMax, IEEE 802.15.4 GTS
    - Token passing
      - e.g. PROFIBUS, HART, FDDI

Hybrid

1. contention-based
   - destructive collisions
     - nodes listen to the medium; if idle, transmit; if collision, backoff
     - CSMA family, e.g. IEEE 802.3, 802.11, 802.15.4 CSMA/CA
     - pros: simple, very flexible
     - cons: not energy efficient (collisions lead to retransmissions); no timing guarantees (non-deterministic); prone to hidden node problem; limited network throughput
   - non-destructive collisions
     - resolve bus conflicts by using a bitwise arbitration; each node has a unique identifier (= priority); Wire acts like a logic AND (0 is dominant, 1 is recessive); transmit identifier bit by bit and hear the medium; if a node sends a ‘1’ but hears a ‘0’, he loses;
     - CAN (cars), HomePlug (domotics), WiDOM (wireless)
     - pros: deterministic, time and energy-efficient
     - cons: synchronization, short tx/rx turnaround time (or 2 transceivers); multiple broadcast domains
WSN technology – MAC aspects

2. contention-free
   ◦ transmissions differentiated in time (TDMA), frequency (FDMA) or coding (CDMA)
   ◦ pre-scheduled access
     • each node’s transmission (which node, starting time, duration) is scheduled a priori
     • TDMA family, e.g. GSM, Bluetooth, WorldFIP, IEEE 802.15.4 GTS
     • pros: energy efficient; timing guarantees; ~100% network throughput
     • cons: not flexible (not adaptable to network dynamics – if scheduling is static)
   ◦ token passing
     • each node transmits during its token holding time; when it expires, token is passed to the next node in a predefined sequence (e.g. logical ring)
     • e.g. PROFIBUS, HART, FDDI
     • pros: energy efficient; timing guarantees; ~100% network throughput
     • cons: not very flexible; very error-prone (token losses) in harsh environments

WSN technology – MAC aspects

3. hybrid
   ◦ merge both previous for more flexibility – best effort/real-time
   ◦ usually CSMA+TDMA, e.g. IEEE 802.16, IEEE 802.15.4
   ◦ pros: best of both worlds
   ◦ cons: management complexity
WSN technology – MAC aspects

- Characteristics of a good MAC/DLL protocol for WSNs
  - **energy efficiency** (to prolong the network lifetime)
    - flexible enough to **adapt duty-cycles** (100% → 0%)
      - dynamically
      - in a per-cluster basis
  - must resolve some causes of energy loss:
    - **collisions** (due to retransmissions)
    - **hidden-nodes** and **exposed-nodes** (lead to unnecessary extra collisions)
    - **overhearing** (wasted effort in receiving a packet destined to another node)
    - **idle listening** (sitting idly and trying to receive when nobody is sending)

WSN technology – MAC aspects

- Characteristics of a good MAC/DLL protocol for WSNs (cont.)
  - **scalability and adaptability**
    - changes in network size, node density and topology should be handled rapidly, transparently and effectively
  - **reliability**
    - error detection/correction mechanisms; order inversion avoidance
  - **traffic differentiation**
    - support higher/lower priority traffic classes; support best-effort and real-time traffic
  - **minimized frame overhead**
    - but still support network management, security, error detection/correction
WSN technology – Physical Layer aspects

- radio link characteristics
  - Link asymmetry
    - node A is connected to Node B does not mean that Node B is connected to node A
  - non-isotropic connectivity
    - connectivity depends on the direction of the signal (at same distance from source)
  - non-monotonic distance decay
    - nodes geographically far away from source may get better connectivity than nodes that are geographically closer

WSN technology – Physical Layer aspects

- propagation phenomena
  - reflection
    - is the change in direction of a wave front at an interface between two different media so that the wave front returns into the medium from which it originated
  - diffraction
    - refer to various phenomena which occur when a wave encounters an obstacle
  - scattering
    - from objects that are small (when compared to the wavelength), e.g.: rough surfaces
WSN technology – Physical Layer aspects

- spatial characteristics

**Connected region (PRR > 90%)**

**Disconnected Region (PRR < 10%)**

**Transitional region (Gray area)**

Cerpa et al. 03

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WSN technology – Physical Layer aspects

- packet reception rate vs. distance

Cerpa et al. 03

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### WSN technology – motes (examples)

<table>
<thead>
<tr>
<th>Node Type</th>
<th>Name</th>
<th>Typical Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialized Sensing Platform</td>
<td>Spec</td>
<td>Specialized low-bandwidth sensor, or RFID tag</td>
</tr>
<tr>
<td>Generic Sensor Platform</td>
<td>Mica, Mica2, MicaZ, Telos, ESB, Firefly, Particle, SquidBee, SHIMMER</td>
<td>General purpose sensing or communication relay</td>
</tr>
<tr>
<td>High-bandwidth sensing/Gateway</td>
<td>iMote1, iMote2, SunSPOT, Stargate1, Stargate2, gumstix</td>
<td>High bandwidth sensing (video, acoustic, vibration), communication, aggregation, computation node or gateway</td>
</tr>
</tbody>
</table>

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### WSN technology – transceivers (examples)

<table>
<thead>
<tr>
<th></th>
<th>CC1000</th>
<th>CC1021</th>
<th>CC2420</th>
<th>TR1000</th>
<th>XE1205</th>
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<tr>
<td>Manufacturer</td>
<td>Chipcon</td>
<td>Chipcon</td>
<td>Chipcon</td>
<td>RFM</td>
<td>Semtech</td>
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<tr>
<td>Operating Frequency [MHz]</td>
<td>300 - 1000</td>
<td>402 - 470/804 - 940</td>
<td>2400</td>
<td>915</td>
<td>433/868/915</td>
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<tr>
<td>Bit Rate [kbps]</td>
<td>76.8</td>
<td>153.6</td>
<td>250</td>
<td>115.2</td>
<td>1.2 - 152.3</td>
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<tr>
<td>Sleep Mode [uA]</td>
<td>0.2 – 1</td>
<td>1.8</td>
<td>1</td>
<td>0.7</td>
<td>0.2</td>
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<tr>
<td>RX [mA]</td>
<td>11.8 (858 MHz)</td>
<td>19.9</td>
<td>19.7</td>
<td>3.8 (115.2kbps)</td>
<td>14</td>
</tr>
<tr>
<td>TX Min [mA]</td>
<td>8.5 (-20dBm)</td>
<td>14.5 (-20dBm)</td>
<td>8.5 (-25dBm)</td>
<td>33 (+15dBm)</td>
<td></td>
</tr>
<tr>
<td>TX Max [mA]</td>
<td>25.4 (+5dBm)</td>
<td>25.1 (+5dBm)</td>
<td>17.4 (0dBm)</td>
<td>12 (+1.5dBm)</td>
<td>82 (+15dBm)</td>
</tr>
</tbody>
</table>

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## WSN technology – ZigBee transceivers

### Ziggbee Chip Comparison - Transceivers

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Device</th>
<th>Series</th>
<th>Code</th>
<th>RAFF</th>
<th>28</th>
<th>28.2</th>
<th>32.3</th>
<th>TX</th>
<th>RX</th>
<th>Voltage</th>
<th>Process</th>
<th>Package</th>
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<td>1.3.x</td>
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<td>AT86C252</td>
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<td>2.1</td>
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<td>1.3.x</td>
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<td>2.1.x</td>
<td>0.125</td>
<td>30.3</td>
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<td>1.8.x</td>
<td>0.125</td>
<td>30.3</td>
<td>30.3</td>
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<td>0.125</td>
<td>30.3</td>
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<td>ChronoLogix</td>
<td>CC2430</td>
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<td>2.0-x</td>
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<td>30.3</td>
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## WSN technology – ZigBee MCU+transceiver

### Ziggbee Chip Comparison - Integrated MCU+Transceiver

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Device</th>
<th>Series</th>
<th>Code</th>
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<th>28</th>
<th>28.2</th>
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<th>RX</th>
<th>Voltage</th>
<th>Process</th>
<th>Package</th>
<th>Package</th>
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<td>WSN Labs</td>
<td>AT86C252</td>
<td>1.3.x</td>
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<td>30.3</td>
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<td>Texas Instruments</td>
<td>CC2531</td>
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<td>ChronoLogix</td>
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<td>0.125</td>
<td>30.3</td>
<td>30.3</td>
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</tbody>
</table>
WSN technology – RFID

- **RFID tag** (or transponder)
  - object that can be applied to or incorporated into a **product, animal, or person** for identification using radio waves
    - from centimeters to meters distance (RFID tag – reader)
    - with or without line-of-sight
  - composed of
    - antenna - for receiving and transmitting the signal
    - integrated circuit (optional) for storing and processing information, modulating and demodulating a (RF) signal, and other specialized functions

---

WSN technology – RFID

- **RFID types**

<table>
<thead>
<tr>
<th>Power Source</th>
<th>Tag Signal Availability</th>
<th>Signal Strength Tag</th>
<th>Required Signal Strength from Reader</th>
<th>Typical Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Tag</td>
<td>Battery on tag</td>
<td>High</td>
<td>Only within field of reader</td>
<td>Useful for standing high-value goods that need to be scanned over long ranges. Example: railway cars on a track.</td>
</tr>
<tr>
<td>Semi-passive Tag</td>
<td>Battery for chip operation. Radio wave energy from reader for communication.</td>
<td>Low</td>
<td>Low</td>
<td>Only within field of reader, less than 10 feet</td>
</tr>
<tr>
<td>Passive Tag</td>
<td>Radio wave energy from reader for operation and communication.</td>
<td>Very low</td>
<td>Very high</td>
<td>Only within field of reader, less than 10 feet</td>
</tr>
</tbody>
</table>

http://java.sun.com/developer/technicalArticles/Ecommerce/rfid

any similarities with WSN nodes?

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WSN technology – RFID

Example applications
- cards (passports, bank, transportation)
- asset management
- identification/tracking (objects/people/animals)
- security/access control
- toll payment
- race timing

Challenges
- reliability
  - certain materials distort or absorb RFID signals, harsh environment, EMI, product packaging and handling, tags/reader relative speed
- cost
  - passive tags: $0.20 - $10 per tag now → < $0.05 per tag in the future
- reinventing processes/applications
  - much beyond bar code replacement
- standardization/integration
  - hardware, communication protocols, system integration
- wearable tags
  - implantable, injectable, digestible,....
- RFID/WSN convergence
  - trend for undefined border (or not) between RFIDs and motes...
Are you ready to be „calmly“ tagged?

WSN technology – MEMS

- Micro-Electro-Mechanical Systems
- integration of mechanical elements, sensors, actuators, and electronics
- NanoEMS, Systems-On-Chip

MEMS applications
- accelerometers (crash sensors, building structures)
- gyroscopes (yaw, gaming, image stabilizer, Segway)
- pressure sensors (tires, blood, surgery incisions force)
- piezoinjectors (inkjet printers, precise drug delivery)
- bioMEMS (cellular manipulation, fluid control)

WSN technology – operating systems

- some OS for resource-constrained WSN devices
  - tens of others...

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Origin</th>
<th>Open source</th>
<th>Real-time</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>TinyOS</td>
<td>UCB, Intel (USA)</td>
<td>Yes</td>
<td>No</td>
<td><a href="http://www.tinyos.net">http://www.tinyos.net</a></td>
</tr>
<tr>
<td>Contiki</td>
<td>SICS (Sweden)</td>
<td>Yes</td>
<td>No</td>
<td><a href="http://www.sics.se/contiki">http://www.sics.se/contiki</a></td>
</tr>
<tr>
<td>Nano-RK</td>
<td>CMU (USA)</td>
<td>Yes</td>
<td>Yes</td>
<td><a href="http://www.nanork.org">http://www.nanork.org</a></td>
</tr>
<tr>
<td>ERIKA</td>
<td>SSSUP (Italy)</td>
<td>Yes</td>
<td>Yes</td>
<td><a href="http://erika.sssup.it">http://erika.sssup.it</a></td>
</tr>
<tr>
<td>MANTIS</td>
<td>UC Boulder (USA)</td>
<td>Yes</td>
<td>No</td>
<td><a href="http://mantis.cs.colorado.edu">http://mantis.cs.colorado.edu</a></td>
</tr>
<tr>
<td>SOS</td>
<td>UCLA (USA)</td>
<td>Yes</td>
<td>No</td>
<td><a href="https://projects.nesi.ucla.edu/public/sos-2x/doc">https://projects.nesi.ucla.edu/public/sos-2x/doc</a></td>
</tr>
</tbody>
</table>
### WSN technology – simulation tools

- some network simulation tools
  - tens of others…

<table>
<thead>
<tr>
<th>Simulator</th>
<th>Origin</th>
<th>Open-source</th>
<th>WSN oriented?</th>
<th>Link</th>
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</thead>
<tbody>
<tr>
<td>OPNET</td>
<td>OPNET Tech. Inc.</td>
<td>No (free for U.)</td>
<td>Yes</td>
<td><a href="http://www.opnet.com">http://www.opnet.com</a></td>
</tr>
<tr>
<td>OMNeT++</td>
<td>TU Budapest (Hung)</td>
<td>Yes</td>
<td>No</td>
<td><a href="http://www.omnetpp.org">http://www.omnetpp.org</a></td>
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<tr>
<td>Castalia</td>
<td>NICTA (Australia)</td>
<td>Yes</td>
<td>Yes</td>
<td><a href="http://castalia.npc.nicta.com.au">http://castalia.npc.nicta.com.au</a></td>
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<tr>
<td>ns-2</td>
<td>USC (USA)</td>
<td>Yes</td>
<td>No</td>
<td><a href="http://nsnam.isi.edu/nsnam">http://nsnam.isi.edu/nsnam</a></td>
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<tr>
<td>SENSORSIM</td>
<td>UCLA (USA)</td>
<td>Yes</td>
<td>Yes</td>
<td><a href="http://rial.ee.ucla.edu/projects/sensorsim">http://rial.ee.ucla.edu/projects/sensorsim</a></td>
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<tr>
<td>GloMoSim</td>
<td>UCLA (USA)</td>
<td>Yes</td>
<td>No</td>
<td><a href="http://pcl.cs.ucla.edu/projects/glomosim">http://pcl.cs.ucla.edu/projects/glomosim</a></td>
</tr>
<tr>
<td>TOSSIM</td>
<td>UCB (USA)</td>
<td>Yes</td>
<td>Yes</td>
<td><a href="http://www.cs.berkeley.edu/~pal/research/tossim.html">http://www.cs.berkeley.edu/~pal/research/tossim.html</a></td>
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<tr>
<td>SENSE 3.0</td>
<td>Remselaer Pi (USA)</td>
<td>Yes</td>
<td>Yes</td>
<td><a href="http://www.itl.cs.rpi.edu/sense">http://www.itl.cs.rpi.edu/sense</a></td>
</tr>
</tbody>
</table>

### WSN technology – network ranges/types

<table>
<thead>
<tr>
<th>Distance between nodes</th>
<th>Nodes located in the same</th>
<th>Network Class (dimension)</th>
<th>Example protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>x μm – x mm</td>
<td>Chip</td>
<td>NanoNetworks NoC (Networks on Chip)</td>
<td>?</td>
</tr>
<tr>
<td>x mm – x m</td>
<td>Body</td>
<td>BAN (Body Area Networks)</td>
<td>IEEE 802.15.4 Bluetooth Low Energy</td>
</tr>
<tr>
<td>x m – x0 m</td>
<td>Room</td>
<td>PAN (Personal Area Networks)</td>
<td>IEEE 802.15.4 Bluetooth Low Energy, IEEE 802.15.4 (ZigBee)</td>
</tr>
<tr>
<td>x0 m – x00 m</td>
<td>Building, Campus</td>
<td>LAN (Local Area Networks)</td>
<td>IEEE 802.15.4 Bluetooth Low Energy, IEEE 802.15.3 (WPAN), IEEE 802.15.4 (ZigBee)</td>
</tr>
<tr>
<td>x00 m – x km</td>
<td>City</td>
<td>MAN (Metropolitan Area Networks)</td>
<td>IEEE 802.15.4/802.11, IEEE 802.20 (WiMAX)</td>
</tr>
<tr>
<td>x km – x… km</td>
<td>Country – …</td>
<td>WAN (Wide Area Networks)</td>
<td>IEEE 802.3 (Ethernet), IEEE 802.15.4 (ZigBee), IEEE 802.20 (WiMAX)</td>
</tr>
</tbody>
</table>

**Tanenbaum**

<table>
<thead>
<tr>
<th>interprocess distance</th>
<th>Provisions located in same area</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td>Single meter</td>
<td>Pervasive area network</td>
</tr>
<tr>
<td>10 m</td>
<td>Rope</td>
<td>Local area network</td>
</tr>
<tr>
<td>100 m</td>
<td>Building</td>
<td>Metropolitan area network</td>
</tr>
<tr>
<td>1 km</td>
<td>Campus</td>
<td>The Internet</td>
</tr>
<tr>
<td>10 km</td>
<td>City</td>
<td></td>
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<tr>
<td>100 km</td>
<td>Country</td>
<td></td>
</tr>
<tr>
<td>1000 km</td>
<td>Continent</td>
<td></td>
</tr>
<tr>
<td>10,000 km</td>
<td>Planet</td>
<td></td>
</tr>
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</table>

WSAN can span over all of these...
WSN technology – wireless standards landscape

- ZigBee
- 6lowPAN
- Wireless HART
- ISA SP100
- IEEE 802.15.4
- IEEE 802.20 (Mobile-Fl)
- IEEE 802.16e (Mobile-WiMAX)
- IEEE 802.16 (WiMAX)
- GSM, GPRS

Bit Rate (Mbps), Energy Consumption

Network Range (m)

0.1 1 10 100 1000 10000

0.1 1 10 100 1000

WSN technology – tiered comm. architectures

these protocols can be combined in multiple-tiered WSN architectures
WSN technology – higher/lower comm. tiers

- higher communication tiers (backbone network)
  - IEEE 802.11/WiFi (QoS limitations)
  - IEEE 802.16/WiMAX (COTS not mature yet)
  - IEEE 802.15.3/UWB (COTS not mature yet)
  - GSM/GPRS
  - wired: switched Ethernet, ATM, FDDI,…

- lower communication tiers (sensor network)
  - Bluetooth Low Energy and IEEE 802.15.6 (formed NOV/2007) – BAN
  - IEEE 802.15.4 (Physical and Data Link Layers) – PAN
  - ZigBee (Network and Application Layers over IEEE 802.15.4)
  - 6lowPAN (light IPv6 over IEEE 802.15.4)
  - Wireless HART and ISA SP100 (over IEEE 802.15.4 PhL)
  - wired: Lon Works, HART, ASI, PROFIBUS, Foundation Fieldbus, DeviceNet, ModBus,…

Quality-of-Service
Quality-of-Service – question

- Please recall Slide #14 (Wikipedia definition of QoS):
  - “QoS is the ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow. …”
- QoS is thus traditionally associated to:
  - bit rate, network throughput, delay, bit/packet error rate
  - which reflect the “performance” properties (timing & error rate)

- So, what do **YOU** think?
  - do these properties alone reflect the overall quality of the service provided to the user/application?

Quality-of-Service – a different perspective

- We consider that this concept of QoS is too strict
  - when taking into the consideration the complexity and scale of emerging computing systems
- Computing systems and particularly WSN applications should be designed taking into consideration other QoS properties, e.g.
  - energy-efficiency/system lifetime
  - dependability (reliability, availability, maintainability, security, safety,…)
  - timeliness (throughput, delay, traffic differentiation, real-time/best effort)
  - scalability, mobility, heterogeneity and cost-effectiveness
- thus, QoS can be viewed in a holistic perspective
  - as elaborated next...
Quality-of-Service – a holistic approach

Quality-of-Service – heterogeneity
Quality-of-Service – heterogeneity

- Heterogeneity emerges from:
  - ≠ networking hardware & software
    - ≠ sensor/actuator-level communication protocols (wired/wireless)
    - ≠ higher-level nodes (e.g. gateways, data processing sinks)
    - ≠ higher-level communication protocols
    - ≠ network planning/management tools
  - ≠ sensor/actuator-level communication protocols (wired/wireless)
  - ≠ higher-level nodes (e.g. gateways, data processing sinks)
  - ≠ higher-level communication protocols
  - ≠ network planning/management tools
  - ≠ embedded system nodes hardware/software architectures
    - ≠ sensors and sensor boards, design diversity, calibration
    - ≠ operating systems (for resource-constrained net. embedded systems)
    - ≠ programming languages (“Idem”) simulation/modelling
    - ≠ middleware (e.g. security and fault-tolerance mechanisms)

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Quality-of-Service – heterogeneity

- Heterogeneity emerges from (cont.):
  - ≠ cyber/pervasive/host computing devices
    - ≠ HMIs (in general), wearable computing (e.g. mobile phones, PDAs, handheld terminals, HMDs, RFID readers)
    - ≠ industrial computers (e.g. PLCs, NCs, RCs) and machinery, mobile robots, transportation vehicles, database servers
  - ≠ applications/services/users in the same system
    - ≠ same network infrastructure may support several applications/services
    - ≠ potentially several/many human users, eventually playing at ≠ levels and with ≠ cultures, ≠ technical skills,...

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Quality-of-Service – heterogeneity

- Research challenges
  - new classes of resource-constrained embedded system nodes must be identified
    - defining (or not?) frontiers between nodes with ≠ characteristics and ≠ capabilities
      - MEMS, active/passive RFID, “general-purpose” motes (e.g. Mica, Telos, Firefly), powerful motes (e.g. iMote, SunSPOT, Stargate)
      - trend for miniaturization will turn this task harder (or easier?)...

Quality-of-Service – heterogeneity

- Research challenges (cont.)
  - interoperability btw sensor/actuator-level comm. protocols
    - experience: there will be no “single” standard protocol for WSNs
    - ≠ wireless protocols will have to coexist
      - e.g. IEEE 802.15.4, IEEE 802.15.6, ZigBee, 6loWPAN, IEEE 802.15.1 & Bluetooth Low Power, ISA100 or WirelessHART
    - ≠ WSN protocols will have to coexist with wired protocols
      - such as for domotics (e.g. KNX, LonWorks), process control (ASi, DeviceNet, HART), industrial automation (PROFIBUS, FF) and automotive (e.g. FlexRay, CAN, LIN, MOST) systems
Quality-of-Service – heterogeneity

Research challenges (cont.)

- interoperability btw sensor/actuator-level and higher-level protocols
  - wireless: IEEE 802.11/WiFi, IEEE 802.16/WiMAX, IEEE 802.15.3/UWB
  - wired: Switched/Industrial Ethernet, ATM
  - guaranteeing end-to-end QoS is even more complex!

- dealing with ≠ embedded system nodes hardware/software
  - ≠ sensor technology
    - for measuring different physical quantities
    - same physical parameter measured by n sensor nodes
      - ≠ type: redundancy, accuracy, functional (e.g. MAX) needs
      - ≠ types: "design diversity" needs
  - ≠ operating systems (e.g. TinyOS, Contiki)
    - ≠ programming languages (e.g. nesC, C, JAVA)
    - ≠ simulation/programming environments/tools

- ≠ applications/services/users in the same system
  - ≠ applications/services will impose ≠ QoS requirements
    - will dynamically change depending on spatiotemporal issues
  - ≠ system designers must adequately devise mechanisms such as MAC/routing, admission control and scheduling, security, fault-tolerance, data aggregation/processing
    - to encompass such applications/services coexistence
  - ≠ several/many human users, playing at ≠ levels and with ≠ cultures, ≠ technical skills, ...
    - further research on Human-Computer Interaction, HMIs, ergonomics, psychology and semantics is required
Energy concerns must always be present

- WSNs = embedded devices at large-scale
  - most will be communicating through air (wireless)
  - some will be mobile
  - additional energy cables are a real burden of even impossible
- therefore
  - most of the devices must be energetically self-sustainable
- but this does not mean that all devices need to be autonomous in terms of energy
  - some devices can (must) be powered by the electrical grid
    - due to special duties (e.g. routers/gateways, data processing)
  - some devices can (must) be powered by special energy sources
    - micro-generators or high capacity batteries/fuel cells/supercapacitors
    - due to inaccessible location, mobility features, etc.
Quality-of-Service – energy-efficiency

- Research challenges
  - hardware design
    - reduce hardware’s energy consumption
      - microprocessors, microcontrollers, DSPs
      - memories, ADC/DAC
    - reduce energy losses
      - mechanical (e.g. friction), electrical (Joule’s), magnetic (Foucault’s)
      - trend for MEMS (when appropriate)
    - favouring active sensors (vs. passive)
      - active sensors produce their own energy
      - thermocouple, piezoelectric, photocell

Quality-of-Service – energy-efficiency (cont.)

- resources utilization
  - sleep as much as possible
    - low duty-cycle computations and communications
  - efficient computations
    - try to reach 100% CPU(s) utilization
      - optimal scheduling algorithms
      - reduce task switching
  - good programming
    - keep it as simple/short as possible
    - avoid unnecessary computations/loops
Quality-of-Service – energy-efficiency

- Research challenges (cont.)
  - resources utilization (cont.)
    - efficient communications
      - energy-aware PhL/MAC/routing protocols
        - use adequate TX/RX power level (→ location-awareness)
        - avoid idle listening & hidden/exposed terminal problems
        - use appropriate routes, the shorter the better (not always)
        - avoid collisions (group nodes in CSMA, contention-free MACs)
    - cross-layer design
      - lighter protocol stacks (< memory footprint, < proc. delays)
  - efficient communications (cont.)
    - communicate only when really needed
      - data aggregation/distributed data processing if possible
      - do not waste bandwidth (specially in TDM-like MACs)
      - operate at low duty cycles (→ synchronization)
    - reduce overheads
      - OSI layer headers (e.g. security and reliability-related),
      - network management messages
  - energy harvesting/scavenging techniques
    - grab energy from environment
      - (e.g. thermal, vibration, light, humidity, wind, waves)

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Timeliness = timing behaviour of a system

- is reflected in properties such as
  - network throughput
    - effective bit rate
  - message delays
    - how long does it take for a message to be transmitted from a source to be received by the destination
  - traffic differentiation
    - assign traffic classes/priorities, e.g., real-time/best effort traffic

- these must be balanced with other QoS properties
  - e.g., to increase throughput, it might be necessary to increase the “hardware” bit rate or nodes duty cycle
  - leading to more energy consumption
Quality-of-Service – timeliness

- Timeliness is of increasing importance
  - in a cyber-physical world, computing entities closely interact with their physical environment, thus their timing behaviour is of paramount importance
  - In some applications, some tasks are imposed to finish within a certain **deadline** – dubbed as “**real-time applications**”
    - need RT computation
    - requiring RT operating systems and programming languages
    - need RT communication
    - requiring RT communication protocols
    - usually require **over-allocation of resources**
      - resulting of the inherent pessimism of the analysis (e.g. WCET)
      - a problem for dynamic and energy-efficient systems

---

**Quality-of-Service – timeliness**

- **Network resources must be predicted in advance** (pre-run-time)
  - to support the applications with a predefined timeliness
  - to guarantee that the system will behave as expected
- **Network dimensioning methodologies/tools**, for computing
  - performance limits (throughput)
  - worst-case **message delays** (end-to-end or per-hop)
  - worst-case routers’ **buffers size**
- Real-time communications require
  - **deterministic** MAC and routing protocols
  - **hierarchical** network models (hexagonal, grid or cluster-tree)
Quality-of-Service – timeliness

- Research challenges
  - biggest challenge is to balance all contradictory QoS properties
  - explore hierarchical network architectures (already referred)
  - investigate how aggregate computations can be used to achieve a time complexity that is independent of the number of nodes
  - design algorithms and protocols in a cross-layer approach; bad thing is that software gets more difficult to maintain and update
  - consider timeliness both at the network and node levels; nodes, hardware design, OS, prog. language and style impact timeliness
  - investigate existing OSs (particularly TinyOS and Contiki) to incorporate real-time features (e.g. preemption, priority-inheritance)
  - find innovative MAC and routing schemes (e.g. to reduce collisions, increase throughput and bandwidth utilization,...)

Quality-of-Service – scalability
Scalability refers to the capability of a system to easily/transparently adapt itself to variations in the
- number of nodes (fewer or more nodes in the overall system)
- nodes’ spatial density (fewer or more nodes in a restricted region)
- geographical region under coverage (smaller/wider, 2D/3D)

So far, largest WSN systems comprise some hundreds of nodes
- e.g. VigilNet, ExScal

Computational and sensing power grows linearly with the number of sensor nodes
- communication capabilities do NOT (they get worse)
- 1000 nodes reporting 1 ms message = 20 minutes!

Research challenges
- efficient scale-aware MAC/routing mechanisms (e.g. WiDOM)
- efficient data processing, aggregation, storage and querying
- explore hierarchical (tiered) network architectures
- support multiple data sinks (need or load balancing)
- investigate how standard and COTS technologies can be used and interoperate to support scalable systems
Quality-of-Service – cost-effectiveness

- System cost usually includes issues such as
  - system design/development
  - hardware cost
  - deployment and commissioning
  - exploration and maintenance

- Research challenges
  - cost/node target < $1 threshold (current cost €10–€50)
  - go for mass production (demand-supply snowball)
  - bet on cheaper designs/materials/production processes
  - bet on components reduction/miniaturization (e.g. MEMS)
Quality-of-Service – reliability

In WSN applications, operational and environmental conditions may be unfavourable:
- vibration/mechanical impacts
- extreme (high/low) temperatures
- extreme (high/low) pressures
- water, humidity, moisture, dust
- other RF sources, EMI

Data delivery in WSN is inherently faulty and unpredictable (much more than in wired networks or even in other wireless networks):
- sensor nodes are fragile and have weak resources
- radio links are error-prone (EMI, obstacles, environment, mobility)
- network congestion (event data bursts) may lead to packet loss
- multi-hop nature of WSNs
Quality-of-Service – reliability

- WSN equipment must be **robust** and **reliable**
  - to overcome all these harsh conditions
  - to reduce or eliminate maintenance actions
  - to have a lifetime of years

- **Robustness** (hardware/software) refers to
  - a component or a system that performs well not only under ordinary conditions but also under abnormal conditions that stress

- **Reliability** is
  - the ability of a component or system to perform its required functions under stated conditions for a specified period of time
    - requires the use of robust hardware/software
    - requires the support for fault-tolerance mechanisms

Quality-of-Service – reliability

- **Research challenges**
  - hardware robustness
    - investigate on robust, cheap, ecological materials/components
    - miniaturization & cost/node should not prejudice hardware robustness
  - robust software/algorithms
    - write “generic” code, to accommodate wide range of situations and thereby avoid having to insert extra code just to handle special cases
    - using formal techniques, e.g. fuzz testing, to test algorithms
    - providing each application with its own memory area (avoiding interference with the memory areas of other applications and kernel)
    - explore advanced programming paradigms (e.g. collaborative computing, reflection mechanisms)
Quality-of-Service – reliability

- Research challenges (cont.)
  - fault-tolerance
    - generically, investigate F-T mechanisms that are scalable, energy/time-efficient, adaptable to dynamic changes
    - F-T mechanisms must spread along different layers (DLL, NL, AL), in a cross-layer approach (exploring the interactions btw layers)
    - find more robust TL solutions that can recover from node/link failures and network congestion

Quality-of-Service – mobility
Quality-of-Service – mobility

- WSN applications may involve a diverse set of mobile entities:
  - vehicles, equipment, animals, humans, fluids,…

- instantiated in:
  - nodes’ mobility
    - isolated or in groups, sensor nodes or gateways
  - data sinks’ mobility
    - on purpose (e.g. data mules) or due to user/application requirements
  - event mobility
    - kind of mobility, e.g. event tracking (e.g. tsunami, gas leak, herd, fire)

- mobility speed:
  - fast: > 20 km/h
  - slow: < 20 km/h

Quality-of-Service – mobility

- Radio-cell/cluster boundaries:
  - intra-cell (or intra-cluster) mobility
    - mobile node moves without losing connectivity with base station
      (structured network) or peers (ad-hoc network)
    - requires no mobility management
  - inter-cell (or inter-cluster) mobility
    - mobile node moves outside the radio coverage of a certain cell/cluster
      into another cell/cluster
    - hand-off (or hand-over) management mechanism is required
Quality-of-Service – mobility

Mobility support can be very helpful, e.g.
- to maintain and repair network connectivity (self-configuration)
- to improve network coverage
- to balance energy consumption (e.g. rotating cluster-heads/routers)
- to adapt to dynamic stimulus changes (collect data upon event)
- to collect data (data mules), extending WSN lifetime
- to increase QoS in critical regions upon events
- to encompass new applications or extend “current” applications’ boundaries with extra capabilities
- ultimately, to increase users’ satisfaction 😊

Research challenges
- mobility support in WSNs is still in its infancy
- investigate on mechanisms for transparent, energy-efficient and reliable mobility support with no network inaccessibility times
  - usually, protocols (e.g. ZigBee) only support joining/leaving of nodes
- analyse how fast mobility can be supported (even harder to tackle)
- investigate new MAC and routing mechanisms that are adaptive to dynamical changes (traffic load, topology) caused by mobility
- develop WSN simulation tools/models encompassing mobility
- find new localization mechanisms that are energy/cost-efficient
- propose accurate radio link quality estimators
  - a basic building block for mobility, for hand-off decisions
Security in WSN applications is much more complex than in today’s “traditional” desktop and enterprise computing:

- systems’ large-scale (nodes/region), wireless, embedded, heterogeneous, unattended, environmentally hostile, dynamic nature
- systems may go beyond boundaries of “controlled” environments
- no “central, trusted authority”
- cost/node precludes robust tamper-resistant casing/protection

WSN systems will require:

- customized solutions: per application, even per node type
- dynamically adaptable mechanisms, reconfigurability
Quality-of-Service – security

- Security breaches
  - security bootstrapping
    - to ensure authenticity, confidentiality, freshness, integrity
    - how to setup secret keys among communicating nodes
  - key management: distribution and revocation
    - faulty or malicious devices must be logically removed from the network
    - to guarantee systems’ reliability and safety
  - secure reconfiguration
    - e.g. remote downloading of authenticated components into a device upon its deployment of relocation
  - intrusion detection
    - to detect attempts to exploit insecurities and warn for malicious attacks
  - secure routing
    - to prevent malicious/faulty devices to perform actions on routed data/packets

Quality-of-Service – security

- Research challenges
  - research on previous topics has not reached maturity
  - low-cost, low power hardware support to security
    - security mechanisms are computationally hungry
    - requires additional hardware to “current” WSN nodes
  - remote program integrity verification
    - existing tamper-resistant hardware is too expensive
    - “lighter” solutions (than existing ones) must be devised
  - balance security with other QoS properties
    - implementing security may imply additional hardware, additional computations, additional communications, longer messages,…
Quality-of-Service – multilateral impacts

Quality-of-Service – invisibility
Quality-of-Service - invisibility

- Invisibility
  - recall Weiser’s vision (Slide #25)
  - “the best computer is a quiet, invisible servant”
  - embed system/components in the environment:
    - invisible (to the human eye)
    - inaudible (to the human ear)
    - ...
  - environmental impact
    - avoiding “buying new is cheaper than maintaining/repairing/recharging”
    - recyclable materials, sustainable systems
    - ecologically friendly (fauna, flora, land, sea, air)

When we get “calm technology”, we can just relax ☺
Ongoing work – COTS4QoS research cluster

- Partners involved: ISEP, NUIG, TUB, UCL, UNIPI
- General Objective
  - achieving Quality-of-Service (QoS) in large-scale distributed embedded systems using standard and Commercial-Off-The-Shelf (COTS) technologies, namely concerning communication protocols, hardware platforms and operating systems
- Short-term (1st year) research
  - radio link quality estimation and characterization
  - integration of the open-ZB (CISTER) and TKN154 (TU Berlin) protocol stacks
  - adding Security functionalities to the open-ZB/TKN protocol stack
  - assessment of standard communication protocols for backbone
- Related links
  - open-ZB toolset: [http://www.open-ZB.net](http://www.open-ZB.net)
  - TinyOS Alliance: [http://www.TinyOS.net](http://www.TinyOS.net)
  - CONET: [http://www.cooperating-objects.eu/research-clusters](http://www.cooperating-objects.eu/research-clusters)

open-ZB

OpenSource Toolset for IEEE 802.15.4 and ZigBee

Ongoing work – CONET highlights

  - book on SOTA and future directions in the CO area
  - first edition to be released soon 😊
  - based on the Embedded WiSeNts roadmap
    - Coordination Action that finished on December 31st, 2006
    - available for free download (use link above)
- CONET newsletter ([http://www.cooperating-objects.eu/newsletter](http://www.cooperating-objects.eu/newsletter))
  - monthly news from the consortium and CO related stuff
  - Issue #1 (January 2009), available for free download (link above)
    - guest column: "When Sensor and Actuator Networks Cover the World" by John Stankovic, University of Virginia
    - roadmap previews "WSN Applications for Healthcare" and "Vision for Innovative Applications on the Aerial Transportation Domain"
any questions?